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"Pushing the Button While Pushing the Argument": Motor Priming of Abstract Action Language

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Abstract

In a behavioral study we analyzed the influence of visual action primes on abstract action sentence processing. We thereby aimed at investigating mental motor involvement during processes of meaning constitution of action verbs in abstract contexts. In the first experiment, participants executed either congruous or incongruous movements parallel to a video prime. In the second experiment, we added a no-movement condition. After the execution of the movement, participants rendered a sensibility judgment on action sentence targets. It was expected that congruous movements would facilitate both concrete and abstract action sentence comprehension in comparison to the incongruous and the no-movement condition. Results in Experiment 1 showed a concreteness effect but no effect of motor priming. Experiment 2 revealed a concreteness effect as well as an interaction effect of the sentence and the movement condition. The findings indicate an involvement of motor processes in abstract action language processing on a behavioral level.

Keywords: Embodiment; Abstract language; Action language; Motor priming; Response times

1. Introduction

1.1. Embodiment of abstract language

Theories of strong embodiment postulate that semantic processing conforms to an ontogenetically learned sensory or motor experience. This indicates that the simulation of a sensory or a motor experience is a prerequisite to successfully comprehend the content of a word or sentence (Barsalou, 1999; Gallese & Lakoff, 2005; Glenberg & Robertson, 1999, 2000; Zwaan, 2004). Strong views of embodiment are supported by results of

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studies using the method of functional magnetic resonance imaging (fMRI) or transcranial magnetic stimulation, showing the activation of primary motor areas while participants process action verbs (Boulenger, Hauk, & Pulvermüller, 2008; Desai, Binder, Conant, Mano, & Seidenberg, 2011; Hauk, Johnsrude, & Pulvermüller, 2004; Tomasino, Fink, Sparing, Dafotakis, & Weiss, 2008). Gallese and Lakoff (2005) discussed that processes of perception and action, simulation, imagination, and linguistic comprehension all make use of the same multimodal neural substrates, including sensorimotor circuits. According to them, this accounts for the processing of action concepts as well as object and abstract concepts. Some of the differences between concrete and abstract language understanding include processing advantages for concrete concepts due to stronger expanded semantic processing (Binder, Desai, Graves, & Conant, 2009; Kiehl et al., 1999) and stronger EEG-related coherence effects between electrodes for concrete than for abstract language, which is explained as resulting from the involvement of more resources in concrete language processing (Weiss & Müller, 2013). In addition, a stronger N400 component has been reported to occur for concrete words due to the integration of more widespread (e.g., sensorimotor) information (Barber, Otten, Kousta, & Vigliocco, 2013). Results of a meta-analysis by Wang, Conder, Blitzer, and Shinkareva (2010) further support the view that the perceptual system, including, for example, the left precuneus, the parahippocampal gyrus, and the fusiform gyrus, is more strongly involved in concrete language processing, whereas abstract language processing is rather linked to a stronger activation of the verbal system, comprising left inferior frontal gyrus, middle temporal gyrus, and the left anterior superior temporal sulcus (also Binder et al., 2009). Also, there seems to be a greater memorability for concrete words which might go back on a higher amount of visual imageability (Richardson, 2003; Wang et al., 2010). Current studies addressing the issue of abstract and metaphoric concepts support the assumption that the degree of embodiment of different concepts is gradual, with more concrete concepts being stronger grounded in the body (Desai, Conant, Binder, Park, & Seidenberg, 2013; Desai et al., 2011; Romero Lauro, Mattavelli, Papagno, & Tettamanti, 2013). This would rather speak in favor of weak notions of embodiment, according to which semantic processing makes use of secondary motor areas only, like the premotor cortex and the supplementary motor area. Accordant evidence has been reported in several fMRI studies (Desai, Binder, Conant, & Seidenberg, 2010; Desai et al., 2013; Sakreida et al., 2013; Tettamanti et al., 2005; Willems, Hagoort, & Casasanto, 2010; Willems, Ozyurek, & Hagoort, 2007). Activations of primary motor areas could only be observed if participants either watched videos of someone executing the action or if they were asked to imagine executing them themselves (Postle, McMahon, Ashton, Meredith, & de Zubicaray, 2008; Willems, Toni, Hagoort, & Casasanto, 2009).

1.2. Facilitation by motor priming

One way to find out about the involvement of cortical motor areas in language processing on a behavioral level is to use the method of motor priming, which has been used in a number of different ways (e.g., Cattaneo et al., 2011; D'Ausilio et al., 2009; Glenberg, Sato, & Cattaneo, 2008; Glenberg et al., 2010; Klatzky, Pellegrino, McCloskey, & Doherty, 1989; Ocampo, Painter, & Kritikos, 2012; Pulvermüller, Shtyrov & Ilmoniemi, 2005; Sato et al., 2011; Tomasino et al., 2008; Wilson & Gibbs, 2007). Some of these studies were language related, but few used behavioral motor priming with regard to action language processing. Klatzky et al. (1989) analyzed the influence of different hand-related actions on language processing. They had subjects train specific hand shapes and primed those hand shapes by verbal hints in the main experiment. Following the primes, subjects had to do a sensibility judgment about a two-word object/action target phrase. Klatzky et al. (1989) reported faster response times (RTs) if a primed hand shape matched the action of the target phrase. To rule out a verbal priming effect, they replicated their experiment using icons as primes. Participants trained the relation of hand shapes to icons prior to the experiment without ever getting any verbal descriptions. However, during the training sessions, subjects might have built up verbal descriptions for their trained hand shapes, which might have accounted for faster RTs. Wilson and Gibbs (2007) reported a similar facilitation effect. They had subjects perform previously learned body movements that were cued by symbols so as not to give any verbal hints. Afterward, participants read a metaphoric phrase containing an action verb and were instructed to press a button as soon as they understood the sentence's meaning. Results revealed shorter comprehension times if the movements matched the action verb used in the metaphoric sentence than if the movements did not match or no movement was performed (Wilson & Gibbs, 2007). Again, when participants were learning which symbol cued which movement, they might have built up a verbal description of their movement, which in turn might have primed the action verb on a lexical instead of a motor level.

Not all motor priming studies revealed a facilitating effect of action execution on action language understanding. Bergen (2007) reported the results of a series of studies, in which interference effects occurred if an action prime preceded a respective verbal action target. He concluded that the sequence of an action-related image and a verbal stimulus as well as temporal constraints are decisive for whether a facilitation or an interference effect would arise. Schaller, Weiss, and Müller (2015) discussed that it might rather be the level of similarity that is decisive, as has already been suggested by Bergen, Narayan, and Feldman (2003). If the image and the verb share action-related semantics, facilitation effects occur, whereas interference effects are elicited if the image and the verb are similar but not equal, that is, for example, sharing the same effector.

There is still growing and convincing evidence for a parallel activation of motor areas —especially secondary motor areas like the premotor cortex and the supplementary motor area—and language areas during concrete and also metaphoric action verb processing (Desai et al., 2010, 2013; Romero Lauro et al., 2013; Sakreida et al., 2013; Tettamanti et al., 2005; Willems et al., 2007, 2010). In this study, we investigated whether evaluated complex movements that require motor processing would similarly influence the process of meaning constitution of action verbs in concrete and abstract contexts. Participants first executed movement primes that were either congruous or incongruous to action verbs embedded in a concrete or an abstract sentence that was presented subsequently. RTs as measured by means of a sensibility judgment task were expected to be influenced by the type of movement performed previous to the sentence. In accordance with the results of former studies, we expected to find a facilitation effect if a congruous prime preceded an action target, which would result in shorter RTs. If the motor components preactivated by the movement are involved in action verb processing both in concrete and abstract contexts, the facilitation effect should occur for both types of target sentences. No effect should occur for abstract control stimuli and we should not see an influence of no-movement primes. In addition, we expected all over shorter RTs for the concrete than the abstract stimuli.

2. Materials and methods

2.1. Experiment 1

2.1.1. Participants

A total of 43 monolingual students (27 females) of Bielefeld University aged 20–32 years (M = 24.5, SD = 2.9) with German as their native language participated in the first RT experiment. Written informed consent was obtained from participants for publication of this study. All were right handed with a mean lateralization quotient of 89.5 (SD = 12.6) according to a modified version of the *Edinburgh Handedness Inventory* (Oldfield, 1971). All subjects declared that they did not suffer from auditory or motor diseases or restrictions that might have had an influence on RTs.

2.1.2. Stimuli

Stimuli were set up as combinations of 197 aurally presented target sentences and 87 video primes. A total of 50 of the 197 sentences were semantically implausible filler items used for a sensibility judgment task. A total of 147 sentences were critical target stimuli. Twenty-nine videos were presented randomly in combination with the 50 filler sentences. These filler videos showed movements irrelevant for and unrelated to the aim of this study and their content is not further discussed. The remaining 58 videos were presented in combination with the 147 critical sentences.

2.1.2.1. Sentences: A total of 147 critical sentences were used as verbal target stimuli. They were recorded with a semi-professional speaker in a sound-attenuated booth. The mean length of sentences was 1,595.5 ms (SD = 207 ms). The critical sentences in the experiment were classified according to the three categories *concrete action*, *abstract action,* and *abstract*. Each of the categories contained 49 sentences. Stimuli were set up as triplets with one sentence out of each category. The category *concrete action* contained 49 sentences like “Ich habe die Handbremse gezogen” (*I have pulled the hand break*), in which an arm-/hand-related action verb was embedded in a literal context. In the *abstract action* category, the action verb was presented in an abstract context, like in “Ich habe die Konsequenz gezogen” (*I have drawn the consequence*). The third category (*abstract*) contained abstract control sentences not including an action verb, like "Ich habe die Konsequenz gefordert" (*I have demanded the consequence*). Twenty-nine action verbs related to the upper limbs were used to generate the target sentences. Their mean length was 734.9 ms (SD = 129.2 ms). A list of the action verbs used is provided in Appendix A. More example stimuli are given in Appendix B. Sentence structure was the same for every item so that the target verb was always positioned at the end.

In a preparatory test, subjects rated the target sentence stimuli as concrete or abstract on a scale ranging from 1 (abstract) to 5 (concrete). A repeated measures ANOVA showed a significant influence of the type of sentence on rating values, $F(2, 52) = 196.59$, $p < .001$. Pairwise comparisons revealed that sentences in the category *concrete action* were rated significantly more concrete (M = 4.62, SD = 0.32) than sentences in the categories *abstract action* (M = 2.38, SD = 0.50) and *abstract* (M = 2.51, SD = 0.55). There was no significant difference between the two categories containing abstract sentences (see Fig. 1). Stimuli of each triplet were matched according to gender of nouns, number of noun syllables, and number of verb syllables. Stimuli of each category were matched according to word frequency of nouns and verbs and cooccurrence of nouns with verbs. For this purpose, the online corpus COSMAS II$_{web}$ (Version 1.8) of the Institut für Deutsche Sprache (IDS) was used (IDS Mannheim, 2003–2012).

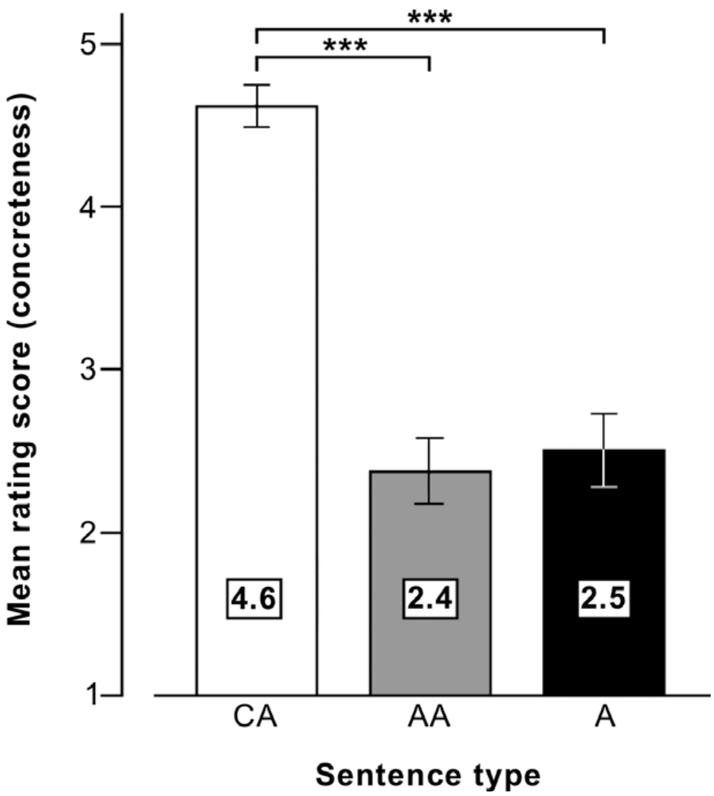

Fig. 1. Mean rating scores for the different sentence types with 1 = abstract and 5 = concrete. *Concrete action* (CA) sentences differed significantly from *abstract action* (AA) and *abstract control* (A) stimuli as indicated by brackets (***$p \leq .001$). Error bars represent a 95% confidence interval.

2.1.2.2. Videos: We presented 58 different critical videos showing movements. Of these, 29 videos showed an anonymized male performing movements that were congruous to the content of the 29 action verbs used in the sentences. Twenty-nine videos showed movements which were incongruous to the same action verbs. The congruous movements were evaluated by means of a preparatory study in which subjects had to listen to verbs and then spontaneously perform an arm and/or hand movement that matched the verb (Weiss & Müller, 2012). For this study, a motion-tracking system in a CAVE (Cave Automatic Virtual Environment) was used (Pfeiffer, Latoschik, & Wachsmuth, 2008). The resulting movements were evaluated according to five modalities and fixed detailed features:

1 *kind of movement* (broad circumscription),
2 *direction* with the features "*away from the body*," "*towards the body*," "*away from each other*" (hands), "*towards each other*," "*up*," "*down*," "*right*," "*left*," and "*in front of the body*" (movements with hands only),
3 *axis* with the features *45°*, *90°*, *135°*, and *180°*,
4 *velocity* with the features *slow*, *average*, and *fast*, and,
5 *number of hands used*.

Those features most often utilized by participants were then used to define the congruous movements. Table 1 shows the evaluation of the verb "zeigen" (*show*) as an example. The evaluation showed that some of the verbs elicited very prototypical movements, that is, almost equal movements by all participants (e.g., *give*, *push*, or *steer*). For other verbs, the actions in response to the verb were more diverse (e.g., *wash*, *harvest*).

The incongruous movements were obtained by manipulating the five features used to define the congruous movements. As a result, they were entirely different from the congruous ones. We conducted a naming study to judge whether the congruous movements would be perceived as more strongly related to the content of the verbs than the incongruous movements. A total of 29 participants watched the action videos and

Table 1
Evaluation of the congruous movement of the verb *to show*[a]

Modalities	Features	Percentage of Times Used
Kind of movement	**to point**	**98.51**
	"to present"	1.49
Direction	**Away from the body**	**100.00**
Axis	**90°**	**100.00**
Velocity	Slow	5.97
	Average	**79.10**
	Fast	14.93
Number of hands	**Unimanual**	**91.04**
	Bimanual	8.96

Note. [a]The left columns show the five modalities and examples of the respective features as performed by participants. The right column displays the percentage of times the feature was performed. Rows in bold display the features used to define the congruous movement.

were asked to write down the first verb that came to their mind. In 20.7% of the cases, verbs given in response to the congruous movements were identical to the target verb. In 15.9% of the responses, participants wrote down a verb that partially overlapped with the target verb ("ver**teilen**"—*distribute* or "auf**teilen**"—*split* instead of "teilen"—*share*; "geben"—*give* instead of "ab**geben**"—*give*). A verb synonymous to the target verb was given in 27.9% of the cases. In contrast, in case of the incongruous movements, neither the target verb nor a verb partially overlapping with the target was ever given as a response. In 99.2% of the cases, verbs given in response to the incongruous movements were different from the target and could not be used as synonyms either. All of the respective paired samples *t*-tests were significant with $p < .001$. According to this outcome, the relation between the target action verbs and the congruous movements was much stronger than the relation between the target verbs and the incongruous movements.

2.1.2.3. Combination of material: The 147 critical target sentences were combined with the 58 video primes showing either congruous or incongruous movements. The combinations of videos and sentences are displayed in Table 2. It is important to note that, although the abstract control sentences are listed once with a congruous and once with an incongruous movement due to the design, in fact none of the movements was congruous to the content of the controls as the controls did not contain an action verb.

2.1.3. Procedure

There were two stimulus lists, as participants should not hear the same sentence in combination with a congruous and an incongruous movement. Thus, the only difference

Table 2
Amount and combination of stimuli in Experiment 1[b]

Action Video Primes	Action Sentence Targets	Example Video	Example Sentence
29 congr. action videos 29 incongr. action vid.	+ 49 concrete action sent.	ziehen/*pull* incongr. #1	+ Ich habe die Handbremse gezogen (... *pulled the hand break.*)
29 congr. action vid. 29 incongr. action vid.	+ 49 abstract action sent.	ziehen/*pull* incongr. #1	+ Ich habe die Konsequenz gezogen (... *drawn the consequence.*)
29 "congr." action vid. 29 "incongr." action vid.	+ 49 abstract control sent.	ziehen/*pull* incongr. #1	+ Ich habe die Konsequenz gefordert (... *demanded the consequence.*)
Total: 58 crucial vid.	+ 147 crucial sent.		
Filler material 29 unrelated action vid.	+ 50 implausible fillers	unrelated #1	+ Ich habe die Frage genäht (... *sewed the question.*)

Note. [b]The "congruous" and "incongruous" action video primes presented in combination with the abstract control sentences were identical to the congruous and incongruous primes presented with the concrete and abstract action sentences. As there was no action verb in the abstract control targets, the actions shown in the video were not truly congruous or incongruous.

between the lists was that in list 1 the sentence "Ich habe die Handbremse gezogen" (*...pulled the handbreak*) was presented in combination with a congruous movement, whereas in list 2 it was combined with an incongruous movement. Participants were randomly assigned to one of the two lists. The distribution of combinations was matched between lists, so that all subjects perceived an equal number of all stimulus types.

Participants had two tasks during the experiment. Their first task was to watch and mirror the movement as seen in the video prime. They were asked to perform the movement themselves as parallel to the video as possible. Their second task was to do a sensibility judgment on the sentence target. Beside the 147 critical target sentences, there were 50 implausible filler items (see Table 2). In a preparatory test, 27 subjects who did not participate in the main experiment rated the 147 critical and the 50 implausible filler sentences on a scale ranging from 1 (implausible) to 5 (sensible). A two-tailed paired samples *t*-test revealed that sensible stimuli were rated significantly more plausible ($M = 4.39$, $SD = 0.38$) than implausible stimuli ($M = 1.29$, $SD = 0.28$), $t(26) = 36.70$, $p < .001$.

After instruction, participants were seated 1 meter in front of a computer screen in an upright position in a sound-attenuated booth. Video recordings of the experimental session made it possible for the experimenter to observe participants during the whole session and to control for careful task fulfillment. To the subjects' right, a computer mouse used for response detection was placed on a small platform at about the height of the subjects' knees so that it was easy to reach. Responses were given with the forefinger and the middle finger of the right hand. As subjects were asked to do a sensibility judgment, the left mouse button (forefinger) represented *sensible* for half of the subjects and *implausible* for the other half of participants.

The experiment was presented via a customized presentation software (*Sculptor*) running under Ubuntu (Version 8.04.2), detecting responses with an accuracy of about 3 ms. Each trial comprised four parts. First, a picture displayed the starting position (2,000 ms). It signaled participants to put their hands on their knees and wait for the video prime to begin. Then, we presented the video showing either a congruous or an incongruous movement. As instructed, participants mirrored the movement and executed it themselves as accurate and as parallel to the video as possible. Each video had a duration of 6,000 ms. As the movements shown in the videos were not of the same length, a varying number of frames was kept before and after the movement to get videos of equal durations. During these frames, the performer in the video remained in the starting position. All videos ended in the starting position, as did participants. Subsequently, a second picture displayed the computer mouse used for response detection (1,500 ms). Participants were instructed to then move their right hand onto the mouse and place their forefinger and middle finger on the mouse buttons. The fourth part was the target sentence. At the end of the sentence, they were instructed to decide whether the sentence was sensible or implausible by pressing the respective mouse button as quickly and accurately as possible. After an ISI of variable length (depending on the length of the sentence) the next trial started. Each trial had a duration of 16 s. Fig. 2 gives an example of a trial.

2.1.4. Data analysis

The statistical analyses were conducted via SPSS 22 on Mac OS X (Version 10.8.5). RTs were measured from verb onset. Two subjects were excluded from the analysis because their error rates exceeded the mean error rate by 2 *SD*. Mean accuracy for the semantic judgment was 91.8%. Tests of normality revealed that only one of the six critical categories had a tendency toward positive skew and kurtosis, which is why we did not consider to transform the data. However, three single responses were excluded due to the outcomes of boxplot analyses, which was about 0.05% of all valid responses on sensible stimuli.

The data were analyzed in a linear mixed model analysis (LMM). The model was built up from a simple model including the fixed factors *video type* (levels: *congruous*, *incongruous*) and *sentence type* (levels: *concrete action*, *abstract action*, *abstract*) to the main model including subjects and items as random intercepts. The different stimulus conditions were included as a repeated measure. The simple model revealed no main effect of *video type*, $F(1, 5482) = 1.399$, $p = .237$, and no interaction effect between the two factors, $F(2, 5482) = 1.670$, $p = .188$. There was only a main effect of *sentence type*, $F(2, 5482) = 119.616$, $p < .001$. Bonferroni corrected post hoc pairwise comparisons for the analysis of the differences between sentence types revealed significant differences between RTs on all three sentence categories with the slowest RTs in the *abstract* category and the fastest RTs in the *action concrete* category (see Fig. 3). Including subjects and items as random intercepts significantly improved the model. This was tested by comparing the −2 Restricted Log Likelihood of the different models. The relationship between the fixed factors and RTs showed significant variance in intercepts across participants, $var(u_{0j}) = 22{,}777$, $\chi^2(1) = 1{,}305$, $p < .01$, and across items, $var(u_{0j}) = 20{,}341$, $\chi^2(1) = 1{,}288$, $p < .01$. However, there was still neither a significant main effect of video type, $F(1, 5130) = 3.507$, $p = .061$, nor a significant interaction between the two factors, $F(2, 3534) = .726$, $p = .484$.

2.1.5. Discussion

Our data from Experiment 1 revealed a significant main effect of *sentence type* with RTs in all three conditions differing significantly from each other. It is well known that

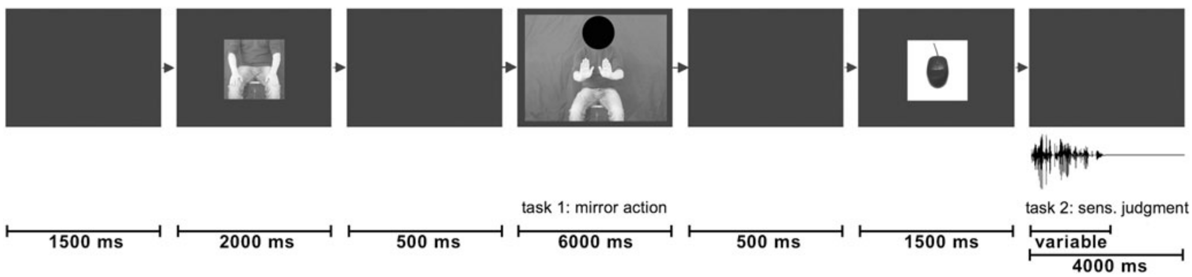

Fig. 2. Design of trials in Experiment 1. Each trial started with a gray screen, followed by a picture displaying the starting position. Subsequently, the video was presented. Participants mirrored the movement parallel to the video and ended in the starting position. Afterward, a picture signaled participants to put their hand on the mouse. Subjects then listened to a sentence and judged its sensibility by a mouse click.

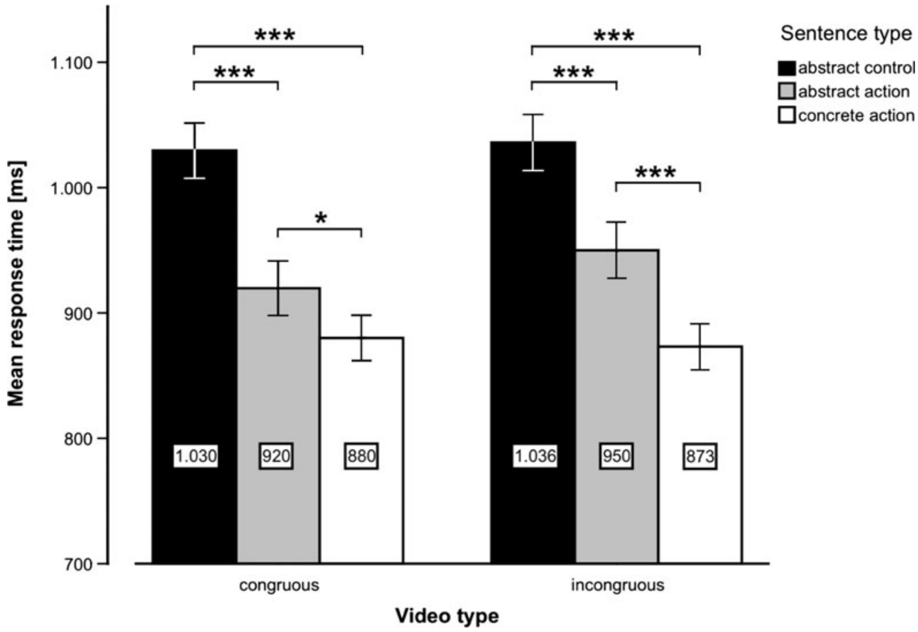

Fig. 3. Mean response times (in ms) for the different sentence types in combination with the two video types in Experiment 1. In both video conditions, all sentence types differed significantly from each other as indicated by brackets (***$p \leq .001$, *$p \leq 05$). Error bars represent the double standard error of the mean.

the processing of abstract language takes longer than that of concrete language (Paivio, 1986; Schwanenflugel, Harnishfeger, & Stowe, 1988). However, although the rating study did not reveal any differences between stimuli in the *abstract action* and the abstract control condition, RTs were significantly faster in the former. This suggests a processing advantage for abstract stimuli containing an action verb, as in all other respects the sentences in the two abstract conditions were the same. This outcome might be a hint on a (partial) interdependency between motor and abstract action language processing.

We could not observe a significant main effect of *video type*. One possible reason could be that there was a problem with the response detection method. Participants responded by a mouse click, which itself is an upper limb-related movement. The concurrent processing of an arm-/hand-related action verb and the execution of an arm-/hand-related movement that was semantically incongruous to the action verb (the mouse click) might have interfered (Klepp, Niccolai, Buccino, Schnitzler, & Biermann-Ruben, 2015; Schaller et al., 2015; de Vega, Moreno, & Castillo, 2013). A second possible reason is that the time span between the executed action prime and the presentation of the action verb was too long. Furthermore, it might be the case that a movement per se, that is, regardless of its semantic content, facilitates language processing due to a higher amount of attentiveness. Such an effect would become apparent only in comparison to a condition, in which no movement is executed, which we did not include in Experiment 1. To correct for these possibly negative influencing factors, we conducted a second experiment.

2.2. Experiment 2

2.2.1. Participants

A total of 32 monolingual students (16 females) of Bielefeld University aged 20–36 years (M = 25, SD = 4.3) with German as their native language participated in the second RT experiment. Subjects were right handed with a mean lateralization quotient of 92.3 (SD = 10.4) according to a modified version of the *Edinburgh Handedness Inventory* (Oldfield, 1971). None of the subjects participated in either the preparatory studies or the first RT experiment. Written informed consent was obtained from the participants for publication of this study. All subjects declared that they were neither under strong medication nor did they suffer from auditory or motor diseases or other restrictions that might have had any influence on RTs.

2.2.2. Stimuli

The same video and sentence material was used as in Experiment 1. In addition to the congruous and incongruous movements, 29 videos showing no movement were presented as a further baseline. Not finding a significant effect between the different video types in Experiment 1 might have been the result of both congruous and incongruous movements facilitating sentence processing due to, for example, a higher degree of attentiveness. A condition in which no action is executed could clarify this possibility. In the still videos, the anonymized male did not perform any movement and simply stayed in the starting position.

2.2.3. Procedure

The procedure and task were almost the same as in Experiment 1. However, instead of using a mouse for response detection, participants stepped on a foot pedal whenever the sentence was sensible. They were asked not to respond if they judged the sentence as implausible. Half of the participants responded with the right and the other half with the left foot.

The structure of trials slightly differed from the structure in the first experiment. Trials started with a gray screen. After 500 ms the video prime started at the position in which the movement began. We eliminated additional frames before and after the movement to shorten the duration of each trial. However, participants successfully mirrored and executed the action primes in the time given. Whenever a still video was presented, participants were instructed to remain in the starting position and wait for the sentence to begin. The action videos ended in a freeze frame of the starting position, which stayed on the screen during the presentation of the sentence and during the successive ISI of 3,000 ms. The sentence target started concurrently with the end of a movement and participants responded by stepping on a foot pedal whenever they perceived a sentence as sensible. Subsequently, a gray screen indicated the beginning of a new trial. The mean duration of the video primes was 3,684.7 ms (SD = 721.0 ms). Accordingly, still videos had a duration of 3,000 ms. Trials had a mean duration of 8,837.5 ms (SD = 882.6). The internal sequence of trials is represented in Fig. 4. This structure allowed us to shorten

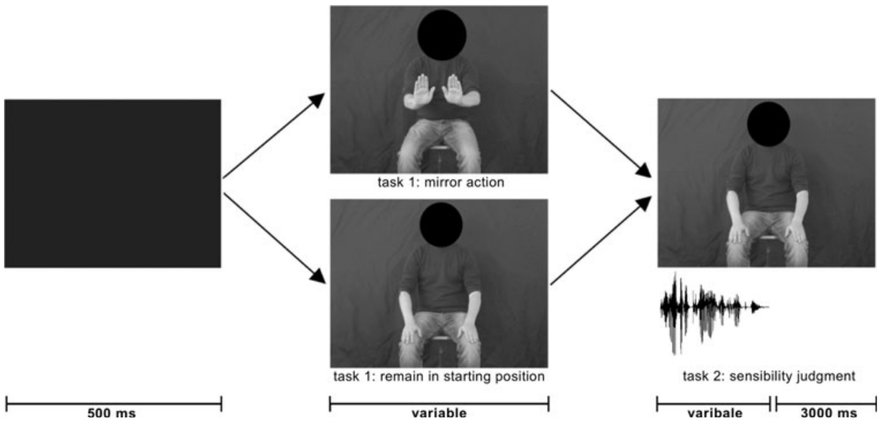

Fig. 4. Design of trials in Experiment 2. After the presentation of a gray screen for 500 ms, the video started. In the no-movement condition, a still video was presented for 3,000 ms. Both the movement and no-movement videos stopped in a freeze frame and the sentence started concurrently. After the sentence, the freeze frame remained on the screen for an ISI of 3,000 ms.

the interval between movement offset and action verb onset and to better reveal a possible priming effect.

2.2.4. Data analysis

Response times were measured from verb onset. Two participants were excluded from the analysis as their error rate exceeded the mean error rate by 2 *SD*.

The mean accuracy for the semantic judgment was 93.1%. Twelve items were excluded due to their error rates exceeding the mean error rate by 2 *SD* (six *abstract action* items and six *abstract* stimuli). As the tests of normality indicated that data in three of nine categories did not meet the criteria of a normal distribution, we corrected for outliers by means of boxplot analyses. Nine single cases were excluded following this analysis, which corresponded to about 0.2% of all valid responses on sensible stimuli.

Subsequently, data were analyzed in an LMM analysis. As in Experiment 1, the model was built up from a simple model including the fixed factors *video type* (levels: *congruous*, *incongruous*, *still*) and *sentence type* (levels: *concrete action*, *abstract action*, *abstract*) to the main model including subjects and items as random intercepts. The different stimulus conditions were included as a repeated measure. The simple model revealed main effects of *video type*, $F(2, 3824) = 6.120$, $p < .01$, and *sentence type*, $F(2, 3824) = 75.133$, $p < .001$, but no interaction effect between the two factors, $F(4, 3824) = 1{,}966$, $p = .097$. Post hoc pairwise comparisons showed significant differences in RTs on all sentence types with slowest RTs in the *abstract* category and fastest RTs in the *concrete action* category. Post hoc pairwise comparisons of the different video types revealed that participants responded significantly faster after executing a congruous or an incongruous movement than after not executing any movement. Including subjects and items as random intercepts significantly improved the model. This was tested by comparing the −2 Restricted Log Likelihood of the different models. The relationship between the fixed factors and RT showed significant variance in intercepts across participants, var

(u_{0j}) = 41,592, $\chi^2(1)$ = 1,099, p < .01, and across items, var(u_{0j}) = 23,430, $\chi^2(1)$ = 585, p < .01. By allowing the intercepts to vary, the model revealed a significant main effect of *video type*, $F(2, 2022)$ = 10.038, p < .001, a significant main effect of *sentence type*, $F(2, 133)$ = 15.924, p < .001, and a significant interaction effect between the two factors, $F(4, 1789)$ = 4.869, p < .01. Separate multilevel models on the different sentence types were conducted to break down the interaction. *Sentence type* as a factor and the interaction term of *sentence type* and *video type* became excluded. Results of these separate analyses are displayed in Fig. 5. Most important, responses on *congruous–concrete action* stimuli were significantly faster than responses on *incongruous–concrete action* and *still–concrete action* items, but there was no difference between *incongruous–concrete action* and *still–concrete action*. However, responses on *congruous–abstract action* sentences were significantly faster than on *still–abstract action* stimuli but not faster than on *incongruous–abstract action* stimuli. No differences between the video conditions were found for the abstract stimuli.

2.2.5. Discussion

Results of the second experiment revealed a main effect of *sentence type* as did the first experiment. Participants were faster to respond to *concrete action* than to *abstract action* and to *abstract action* than to *abstract* stimuli, which corresponds to a concreteness effect. Furthermore, the finding of a processing advantage for abstract sentences containing an action verb could be reconfirmed.

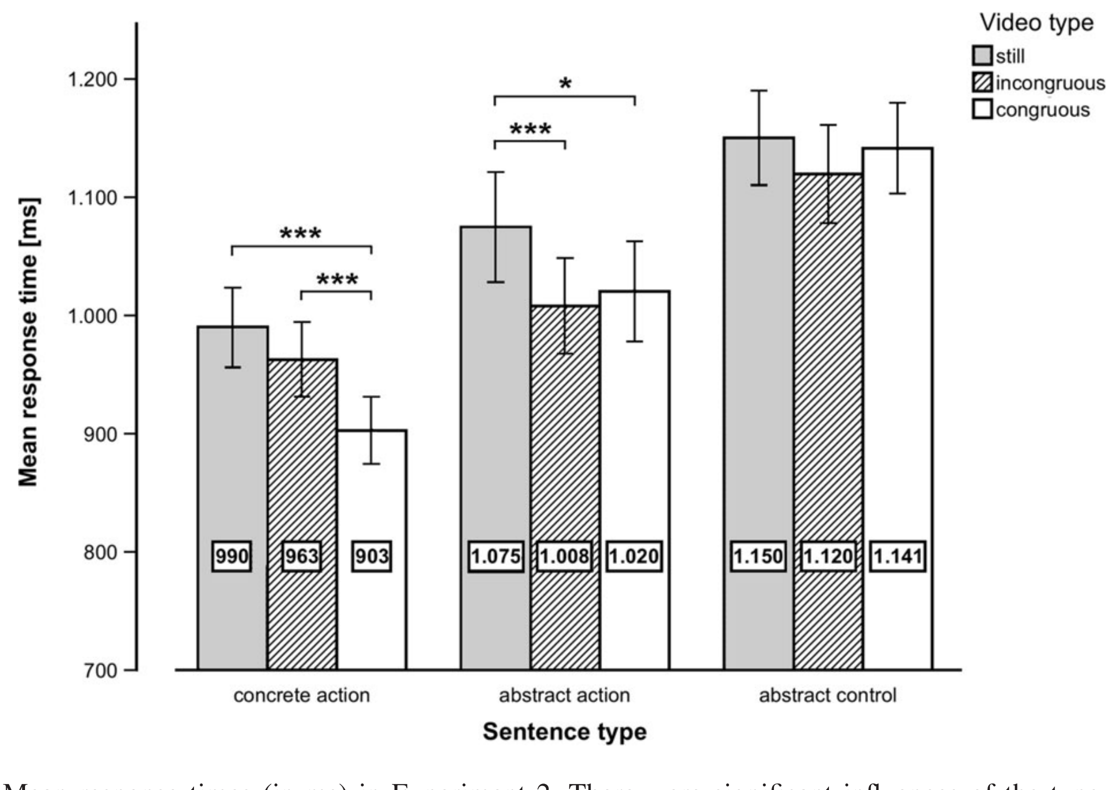

Fig. 5. Mean response times (in ms) in Experiment 2. There were significant influences of the type of video on the concrete action as well as the abstract action stimuli but not on the abstract control items as indicated by brackets (***$p \leq .001$, *$p \leq 05$). Error bars represent the double standard error of the mean.

An additional finding was the main effect of *video type*, which we did not observe in the first experiment. Participants were all over faster to respond to stimuli preceded by congruous and incongruous movements than to stimuli in the no-movement condition. However, this facilitation effect did not equally occur for the three sentence types presented in this study, as the interaction effect showed. An influence of movement execution could only be observed for the *concrete action* and the *abstract action* stimuli but not for the non-action *abstract* items. Thus, a facilitation effect only occurred for sentences containing an action verb. This finding indicates that processes related to action execution and concrete as well as abstract action language processing are linked to each other and that cross-modal priming may occur between the two modalities. The observation that our method of motor priming worked in the second but not in the first experiment might be due to the reasons discussed earlier. First, the mouse click itself might have interfered with the concurrent processing of the action verbs related to the upper limbs. As discussed by de Vega et al. (2013), interference effects might occur as a result of concurrent action language processing and action execution. Second, the long time interval between movement offset and action verb onset in Experiment 1 might have prevented a facilitation effect to become apparent. A third point might have been the missing no-movement condition in Experiment 1. In the second experiment this baseline served as a neutral comparison condition.

The processing of *concrete action* and *abstract action* stimuli was differently influenced by the kind of movement that was executed in Experiment 2. If participants performed a congruous movement before a *concrete action* sentence, this movement facilitated the sensibility judgment in comparison to the incongruous and the no-movement condition. Performing an incongruous movement before a *concrete action* stimulus did not have this facilitating influence. In contrast, the execution of both a congruous and an incongruous movement facilitated the sensibility judgment on *abstract action* items in comparison to the no-movement condition. The processes underlying action execution thus seem to be relevant to a different degree or in different ways for concrete compared to abstract action language processing.

3. General discussion

This study focused on mental motor processes during meaning constitution of action verbs in abstract contexts. We conducted two experiments in which we primed cortical motor processes in the brain by use of a motor priming task.

Two aspects need to be discussed when interpreting motor priming data. The first relates to the question whether the observed effect might be an effect of lexical instead of motor priming. In some earlier motor priming studies, icons or symbols were used to initiate a previously learned movement so as to circumvent a lexical priming of action verbs (Klatzky et al., 1989; Wilson & Gibbs, 2007). However, during the training sessions, participants might have developed some verbal circumscription for the movements in the form of *“Icon x corresponds to flexing my fingers as though I’m grasping* *something*." In the experimental session, this might have primed the action on a lexical level and thus the observed effects might not go back on a preactivation of motor but of language-related areas in the brain. In this study we aimed at circumventing this problem by (a) not using any symbols or icons and thus not training participants before the main experiment and (b) by not giving them enough time to think about the movement they were executing. The possibility that the action verbs were primed on a lexical level cannot be entirely ruled out by this approach. In our opinion, though, the current results speak in favor of an avoidance of lexical priming by the use of our motor priming method: In Experiment 1, we could not observe any RT differences between the congruous and the incongruous movement condition, suggesting that watching a movement did not elicit a lexical representation of the respective verb. As the time interval between movement offset and verb onset was quite long in Experiment 1, the respective data should be interpreted with caution, though. However, in Experiment 2, incongruous movements primed action verb comprehension in abstract contexts, which cannot be an effect of lexical priming and thus speaks in favor of our method as well. The second aspect that needs to be discussed is whether it might have been the movement per se without regard to its content that facilitated comprehension, possibly due to a higher degree of attentiveness. Our data do not speak in favor of this assumption. In Experiment 2, only congruous movements had a facilitating effect on the comprehension of *concrete action* sentences. In addition, RTs on *abstract* sentences were not influenced by any type of movement in comparison to the no-movement condition. We conclude that language comprehension is not facilitated by the preceding execution of any kind of movement. Instead, the content of the movement and the content of the verbal stimulus need to be equal at least to some degree (Bergen et al., 2003; Schaller et al., 2015).

3.1. Limitations concerning Experiment 1

In Experiment 1, the three sentence types *concrete action*, *abstract action*, and *abstract* were presented in combination with the two video types *congruous* and *incongruous*. We observed a significant main effect of *sentence type* which reflects the well-known concreteness effect. The difference between the *abstract action* and the non-action *abstract* stimuli indicates a processing advantage for the abstract stimuli containing an action verb. Consequently, we suggest an involvement of motor processes in action verb comprehension in both concrete and abstract contexts, which support the process of meaning constitution. However, no conclusions regarding the degree or the way of motor involvement during abstract action language processing could be drawn from the data of Experiment 1, as we did not observe an effect of *video type*. This might be a consequence of the design. In previous studies, a somatotopic activation of motor areas has been detected during action language processing, that is, motor areas processing hand-related actions became active during hand action verb processing (Boulenger et al., 2008; Hauk et al., 2004; Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005). Consequently, we had subjects perform congruous arm-/hand-related movements to prime the comprehension of corresponding arm-/hand-related action verbs. However, the mouse click participants executed as a sensibility marker was an arm-/hand-related movement, which might have interfered with the parallel processing of the action verb (Klepp et al., 2015; Schaller et al., 2015; de Vega et al., 2013). If this was the case, no influence of the type of movement became detectable because each action verb was combined with the same movement, that is, the mouse click. This would also speak in favor of the assumption that action execution is primed by action language processing on a detailed motor level and vice versa, as was suggested by Bergen and Wheeler (2005). An incongruous movement of the arm and/or the hand, as our response movement, may not facilitate arm-/hand-related action verb processing. Instead, the movement and the verbal stimulus need to share semantic content. Furthermore, this finding is relevant for future motor priming studies, as the response and the action content should not relate to the same effector. Another design-related problem may have occurred because the time span between movement offset and action verb onset amounted to about 2,400 ms, which is much longer than, for example, in ACE-related studies. After this interval, a priming effect might have been too weak to become detected.

3.2. Facilitation versus interference

In Experiment 2, the same sentence types as in the first experiment were combined with the three video types *congruous*, *incongruous*, and *still*. In contrast to Experiment 1, participants indicated their sensibility judgment by stepping on a foot pedal. Data revealed a main effect of *sentence type* as well as of *video type* and an interaction effect of the two factors. As for the main effect of *sentence type*, the same explanation as in Experiment 1 holds true. The main effect of *video type* might have been the result of cortical motor processes, which became activated by participants' movement execution, also accounting for the processing of the action language targets presented subsequently. This is in accordance with other findings concerning cross-modal priming as described in several ACE and other motor priming studies (e.g., Bergen & Wheeler, 2005; Glenberg & Kaschak, 2002; Glenberg, Sato, Cattaneo, et al., 2008; Klatzky et al., 1989; Wilson & Gibbs, 2007).

As Bergen et al. (2003) claimed, cross-modal priming may only occur if the motor representation activated by a prime and the motor representation needed for processing a target are the same, that is, share semantic content. The activation of neurons responsible for coding a certain motor representation is thought to inhibit motor representations which are very similar. According to this view, a prime which is only similar but not equal to a target would lead to its inhibition (Bergen et al., 2003). This might be the case whenever interference effects can be observed. Our results partly confirm the assumption that facilitation effects occur only if an action and a verbal stimulus share semantic content. Comprehension of *concrete action* stimuli was facilitated only if the verbal target was preceded by a congruous action prime but not if it was preceded by an incongruous action prime. In comparison to the no-movement condition, however, incongruous movements did not lead to interference effects as would be expected against the background of what has been proposed by Bergen et al. (2003). After all, the incongruous movements were related to the same effector as the subsequent action verb, that is, arms and hands. It is possible, though, that the semantic content of the incongruous movements used in this study was not clearly defined. As we more or less made these movements up so as to make sure they were completely unrelated to the congruous movements, their motor representations might not correspond to any conventionalized definition. They might have evoked quite diffuse motor representations not having the power to inhibit similar motor representations. In contrast, Bergen et al. (2003) used clearly defined movements as "unrelated" action primes. Another finding was that the comprehension of the *abstract action* items was equally facilitated if participants performed a congruous or an incongruous movement. It thus seems to be the case that the hypothesis of a shared semantic content being a prerequisite for facilitation effects holds true for concrete action language only.

Whether a facilitation or an interference effect is observed may also be a matter of timing. Borreggine and Kaschak (2006) tested the ACE with requesting participants to respond at four different time points: immediately after sentence onset and 50 ms, 500 ms, and 1,000 ms after sentence offset. They observed facilitation effects for the first two time points, but interference effects 500 ms and 1,000 ms after sentence offset. Borreggine and Kaschak (2006) give the explanation that the completion of the motor program simulation needed for action sentence comprehension leads to this simulation being temporarily unavailable so that the processing of respective motor commands will be delayed. In contrast, compatibility effects would occur if the two processes occurred simultaneously. A similar experiment with different outcomes was reported by de Vega et al. (2013). In contrast to the study by Borreggine and Kaschak (2006), they observed interference effects if a motor response congruous to the content of the sentence had to be given 100 or 200 ms post-sentence offset and a small facilitation effect 350 ms post-sentence offset. Thus, it seems that facilitation versus interference effects cannot be explained by a single factor alone, like timing or semantic overlap. Rather, different factors seem to influence the kind of interaction of motor and language processes.

3.3. Motor representations and abstract action language

The involvement of motor processes in the comprehension of abstract action language thus seems to differ from the involvement in concrete action language comprehension with regard to the degree or quality of participation. Dove (2015) discussed that the engagement of embodied representations in various cognitive tasks may vary depending on factors like the context, the task, and the relative abstractness of concepts. This is in accordance with results of fMRI studies proposing a gradual involvement of motor areas in abstract action language processing (Desai et al., 2011, 2013; Romero Lauro et al., 2013; Sakreida et al., 2013). Sakreida et al. (2013) compared brain activity during concrete, mixed, and abstract noun–verb combinations. They observed activation of the left precentral gyrus and the supplementary motor area in the premotor cortex during the processing of concrete and abstract noun–verb combinations (CA, AC), suggesting a supporting role of these areas in action language understanding. Desai et al. (2011) compared brain activation patterns related to the processing of literal action and metaphoric action sentences that contained an arm-/hand-related action verb. They found that both sentence types elicited activation in the anterior inferior parietal lobule (aIPL) in the left hemisphere to the same degree. During metaphoric action processing, though, Desai et al. (2011) reported an activation of the right aIPL in addition to other areas related to abstract language processing. They further observed that the involvement of sensorimotor areas in action metaphor comprehension is gradual, with a stronger involvement during the comprehension of more unfamiliar metaphors. In a later study, Desai et al. (2013) enhanced this assumption. In addition to literal and metaphoric action stimuli, they presented idiomatic action sentences to participants. They observed activation in secondary motor areas in the IPL, small activation clusters in primary motor cortex, and in temporal regions for both literal and metaphoric stimuli but not for idiomatic sentences, which further supported the idea of a gradual involvement. Romero Lauro et al. (2013) obtained similar results. In their fMRI study, participants read four different types of sentences: idiomatic, metaphoric, literal, and fictive motion stimuli. All stimuli contained action verbs describing either actions performed with the upper or the lower limb. The data showed that literal sentences caused a somatotopic activation of the left precentral gyrus for both upper and lower limb-related verbs. For metaphoric stimuli this effect was limited to upper limb-related action verbs. Fictive-action verbs elicited an activation of the premotor cortex. No significant activation of motor areas was found for idiomatic sentences. Romero Lauro et al. (2013) concluded that motor areas are stronger involved in concrete than in abstract action verb processing and that the involvement is gradual, ranging from strong in literal sentences to weak or no involvement in idiomatic sentences. Our results may be interpreted as being in line with this gradual approach. Whereas only a congruous movement facilitated concrete action verb comprehension, both congruous and incongruous movements had a positive effect on comprehension processes concerning *abstract action* items. This suggests that detailed motor representations are linked to concrete action language processing, whereas abstract action language processing might be linked to rather broad motor representations. Troyer, Curley, Miller, Saygin, and Bergen (2014) came to a similar conclusion. They used point light walkers as visual action primes and had participants read literal and metaphoric action sentences. Whereas in the literal condition a close relation between prime and target leads to interference effects, it speeded reading times in the metaphoric condition. If the relation between prime and target was distant, the opposite effects occurred. However, Dove (2015) emphasized that the answer on whether sensorimotor processes are involved in meaning constitution processes related to abstract action concepts might not be answered that easily and that a more fine-grained perspective is needed, taking into account factors like the task, the context, and current goals.

These assumptions are in agreement with a weak view of embodiment (Meteyard, Rodriguez Cuadrado, Bahrami, & Vigliocco, 2012), which, against the background of the current findings, we would support as well. Our results suggest that, at least for the *abstract action* stimuli, some sort of abstraction process occurs and that the language input is integrated in a holistic manner rather than being processed solely by means of sensorimotor support.

4. Conclusion

We investigated the involvement of mental motor processes in meaning constitution of action verbs in abstract contexts in two behavioral experiments. It became obvious that motor priming does not only work for action verbs in concrete but in abstract contexts as well. Thus, the results of our study speak in favor of sensorimotor processes being recruited during abstract action language comprehension. Our results further revealed that the assumption of a shared semantic content between an action and a verbal stimulus being a prerequisite for successful motor priming (Bergen et al., 2003; Schaller et al., 2015) holds true for concrete action language only.

In accordance with other studies related to abstract action language processing, we assume that there are differences in the degree or quality of the retrieved motor representations in action verb comprehension in concrete compared to abstract contexts. Whereas action verbs in literal sentences elicit a very detailed motor representation, action verbs in abstract sentences are processed by retrieving a rather broad motor representation, possibly limited to the effector involved in action execution. Our findings support a weak view of the embodiment theory, as action verbs in abstract contexts do not make the same demands on sensorimotor processes as action verbs in concrete contexts do.

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Appendix A: List of action verbs used in the sentence targets

abbrechen—*break off*	fällen—*fell*	schließen—*close*
abgeben—*give*	fassen—*grasp*	schmeißen—*throw*
ablegen—*lay down*	geben—*give*	senken—*lower*
abnehmen—*take off*	halten—*hold*	steuern—*steer*
aufheben—*pick up*	heben—*lift*	streichen—*paint*
begraben—*bury*	hochhalten—*hold up*	teilen—*share*
berühren—*touch*	lenken—*steer*	waschen—*wash*
drücken—*push*	nehmen—*take*	zeigen—*show*
ergreifen—*catch*	öffnen—*open*	ziehen—*pull*
ernten—*harvest*	schlagen—*hit*	

Appendix B: Examples of sentence stimuli

Verb	Concrete Action	Abstract Action	Abstract Control
teilen *share*	Ich habe die Beute geteilt *I have shared the goods*	Ich habe die Ansicht geteilt *I have shared the opinion*	Ich habe die Ansicht gestärkt *I have supported the opinion*
streichen *paint*	... die Fassade gestrichen *... painted the front*	... die Beihilfe gestrichen *... cancelled the allowance*	... die Beihilfe abgelehnt *... refused the allowance*
geben *give*	... das Autogramm gegeben *... given the autograph*	... das Versprechen gegeben *... given the promise*	... das Versprechen erneuert *... renewed the promise*
nehmen *take*	... den Rucksack genommen *... taken the backpack*	... den Urlaub genommen *... taken the holiday*	... den Urlaub genossen *... enjoyed the holiday*